SELECTED PROBLEMS IN EXPERIMENTAL INTERMEDIATE ENERGY

PHYSICS

DOE/ER/40836--T1

PROGRESS REPORT

SEPTEMBER 1995

**GRANT PERIOD:
FEBRUARY 1, 1994 - JANUARY 31, 1997**

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USDOE Report No. ORO-3948-25

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I. Personnel

Personnel who will have worked in support of this contract for the period February 1, 1994 to January 31, 1997 are listed below.

E. V. Hungerford	Professor of Physics
B. W. Mayes	Professor of Physics
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II. Background

A complete description of the research program of the intermediate energy group at the University of Houston may be found in previous progress reports, renewal proposals, and proposals to the various accelerator advisory committees. Recent documents are appended to this report and summaries of current research activities are presented in the next section. The objectives of the research program are to: (1) investigate selected, forefront problems in experimental intermediate energy physics; (2) educate students in this field of research; and, (3) develop the instrumentation necessary to undertake this experimental program.

Generally, the research is designed to search for physical processes which cannot be explained by conventional models of elementary interactions. As one example, we use nuclear targets where the nucleus provides a many body environment of strongly interacting particles, and where one attempts to observe the perturbation of a known interaction by this environment. These effects, however, may be masked by the complexity of the many body problem and may be difficult to observe. Therefore,

experiments of this type must be carefully chosen and analyzed for deviations from the more conventional models.

There were three major thrusts of the program: (1) strange particle physics, where a strange quark is embedded in the nuclear medium; (2) muon electro-weak decay, which involves a search for a violation of the standard model of the electro-weak interaction; and, (3) measurement of the spin dependent structure function of the neutron and proton. During this grant period, approximately 30% of our effort has been expended on the MEGA experiment, a search for lepton number violating decay, $\mu \rightarrow e\gamma$ at the Los Alamos Meson Physics Facility, LAMPF. Approximately 50% of our effort has been devoted to strange particle physics, mainly at the Brookhaven Alternating Gradient Synchrotron, AGS. The remaining 20% has been spent on the measurement of the spin dependent structure function of the neutron and proton, SMC, at CERN. The status of our research activities is summarized in Tables I and II. Table I shows those experiments which were under active investigation during the grant period, and Table II lists approved experiments and experiments to be undertaken by the research group in the future.

The group has been active in experiments at LAMPF, AGS, and CERN. In addition, we are preparing to mount experimental programs at the Continuous Electron Beam Facility, CEBAF, and we are presently running E907 at the Alternating Gradient Synchrotron, AGS. Both of these later programs involve the study of strange baryons in the nuclear medium; hypernuclei. The CEBAF program is designed to take advantage of the expected performance of the CW electron beam at that accelerator to provide high resolution studies of hypernuclear spectra. The research requires the development of a spectrometer system, and the experiments are capable of providing resolutions an order of magnitude better than currently possible at hadronic machines. The program is discussed in more detail in the next section.

The program at the AGS uses the neutral meson spectrometer, NMS, constructed at LAMPF and moved to the AGS. This provides the first experiments using the (K^-, π^0) reaction (charge symmetric to the (K^+, π^-) reaction) which will create new hypernuclei to be studied with excellent resolution. The Mega experiment, a search for lepton number violation, is under data analysis. In particular our group continues to develop techniques to improve and understand the axial spatial resolution of the photon detector layers which we constructed for the experiment. The Houston group provided the muon chambers for the CERN experiment, NA47. This is the last year this experiment will acquire data, but analysis is expected to continue into 1997.

In summary, the group has been active in programs attacking a diverse range of problems at several different accelerator facilities. Emphasis on programs, as measured by effort expended, reflects the requirements to meet our commitments to a specific experiment. For example, MEGA previously used substantial resources in manpower and funds, but now since MEGA has concluded data acquisition we have allocated one FTE person to the data analysis. At the moment we have a major commitment to bring AGS E907 to operational status, and this will require a majority of our resources in 1996 and 1997. The focus of our future work will be on experiments at CEBAF and BNL.

Table I. Experiments Completed or under Analysis During the Grant Period

Experiment	Description	Status
AGS Exp 774	Search for Sigma Hypernuclei	Paper Published Paper in Preparation
AGS Exp 874	K+ Elastic and Quasifree Scattering	Paper Published Paper Accepted Data Under Analysis
AGS Exp 887	Do Narrow (Hypernuclear states exist?	Data Under Analysis
LAMPF Exp 969(MEGA)	Search for $\mu \rightarrow e\gamma$	Papers Published Papers in Preparation Data Under Analysis
LAMPF Exp 1240	Measurement of the Michel Parameter, Rho	Data Under Analysis
CERN Exp NA47	Spin Dependent Structure Functions of the Neutron and Proton	Papers Published Papers in Preparation Data Under Analysis
AGS Exp 907	Investigation of Hypernuclei by the (K^-, π^0) Reaction Using Stopped Kaons	Data Under Analysis Experiment Running

Table II. Approved Experiments

Experiment	Description	Status
CEBAF Exp 89-9	Spin Dependence of p Shell Hypernuclei	Approved
CEBAF Exp 93-18	Kaon Electroproduction, Longitudinal and Transverse Cross Section Separation, and the Kaon Electromagnetic Form Factor Determination in $((e,e'K+)\Lambda$	Approved

III. Selected Abstracts of Current Research

This section reviews in more detail the experimental programs in which the group has been involved during the grant period.

A) Strangeness Interactions in Nuclei

1) Hypernuclear Physics

The level structure of hyperons embedded in a nucleus (hypernuclei) has been under investigation by our group for some time¹. The motivation has been to sort out the hyperon-nucleon interaction in the many body system. Although hypernuclear structure is interpreted by conventional nuclear many-body techniques, the underlying quark structure in this interaction is just beginning to be addressed. It was suggested some time ago² that by placing a hyperon into what would otherwise be an indistinguishable sea of up and down quarks, unique configurations of the strange quark due to the interaction of the Pauli principle may provide the key to unlock the quark picture of the nucleus. For example, one would like to determine the deeply bound level structure of hypernuclei with high precision. Differences in this structure from conventional calculations due to partial de-confinement of the quarks in the Λ , might occur. Alternatively, a change of the size of the Λ in the nucleus may possibly be explained in terms of $\Lambda\Sigma$ coupling³ or perhaps three body forces⁴. This could also be connected to the significant charge symmetry breaking observed in the Λ -nucleon interaction⁵.

The fundamental baryon-baryon interaction, with the exception of the nucleon-nucleon interaction, is not well known. Of importance to hypernuclear physics is how SU(3) flavor symmetry is broken by the substitution of a strange quark for an up or down quark in a nucleon. In the mutual interactions among the neutron, proton, and lambda, SU(3) symmetry can be used to relate the coupling constants, but in a one boson exchange model, the exchange of the vector and scalar mesons are still not uniquely specified, and it will probably not be possible in the short term to obtain lambda-nucleon scattering data of sufficient quality to resolve this issue. However, Λ -hypernuclei provide a unique laboratory to study the hyperon-nucleon interaction, as well as address other fundamental issues.

Due to the absence of one pion exchange (OPE), the Λ -N interaction is short ranged. Therefore in the nuclear medium, the coupling of a lambda to a sigma, $\Lambda N \leftrightarrow \Sigma N$, and the three body ΛNN interaction (all of these descriptions may be substantially equivalent) are important in determining the properties of the hypernuclear system. In addition the strangeness degree of freedom allows the particles to rearrange themselves in order to maximize the nuclear binding energy. Thus the hypernuclear system can emphasize rather different fundamental physics from conventional nuclei. For example, the hyperon spin-orbit interaction is smaller, but charge symmetry breaking is larger than in a similar nuclear system. Therefore systematic studies, comparing spectra from different reaction mechanisms are needed to understand the open questions. Furthermore, precise measurements of the properties of heavy hypernuclei can provide

information about the interior of a nuclear system, which is quite difficult to obtain by other means. Finally a better understanding of the hyperon and kaon nucleus interaction is also important for the development of the theory of neutron stars, where hyperon and kaon condensates might be expected to play significant roles.

The best published resolution in previous hypernuclear counter experiments has been about 2 MeV in the carbon system, and closer to 5 MeV in heavy hypernuclei. These spectra are produced by the hadronic reactions, (K^-, π^-) and (π^+, K^+) . As both of these reactions provide little spin-flip amplitude in the forward direction, they predominantly produce natural parity states. However the (K^-, π^-) reaction has low momentum transfer, so substitutional states are excited, while in the high momentum transfer reaction, (π^+, K^+) , states of "stretched" spin are preferentially excited. On the other hand, the $(e, e'K)$ reaction allows unnatural parity states to be observable for the first time.

The best evidence that single particle Λ hypernuclear states exist in heavier nuclei comes from the analysis of the structure observed in our experiment involving the (π, K) reaction on heavier nuclear targets, AGS Exp 798. This reaction populates a series of levels associated with the removal of a valence neutron and the deposition of a Λ in one of the possible shells within the nucleus. An example⁶ is that of ^{89}Y where a $g_{7/2}$ neutron is removed and the Λ is placed in shell orbitals from the 1s to the 1g shell, Figure 1. Fine structure within these levels cannot be seen with the current resolution; however, the centroid of the various Λ -shell orbitals as a function of the atomic mass can be fit with a spin-independent Λ -nucleus optical potential of Woods-Saxon form, Figure 2. The level spacings vary smoothly as a function of A , signifying single particle behavior. However, it is not possible to simultaneously fit both of the spectra of light and heavy hypernuclei with a potential linear in the nuclear density. A repulsive density dependence is needed to reduce the over-binding problem in nuclear matter. Such terms are consistent with a repulsive three-body ΛNN interaction, and similar terms are needed in the light hypernuclear systems⁸. With this complexity the observed deeply bound Λ states are well defined.

The investigation of strangeness in nuclear systems is not merely an extension of conventional nuclear physics. Certainly one cannot, nor would one want to, reproduce the wealth of information that has been accumulated on conventional nuclei. The hypernucleus, however, offers a selective probe of the hadronic many-body problem, providing insight in areas that cannot be easily addressed by conventional techniques. Such questions as isobar mixing, charge symmetry breaking, and quark confinement are more important, and thus more evident, in strange hadronic matter. What is now needed is a series of studies at high resolution in heavier hypernuclei, and the comparison of spectra produced with different reaction mechanisms. Spectroscopy and the complete investigation of various weak decay channels should be investigated with precision.

Electromagnetic production of hypernuclei provides the opportunity to precisely study the transition form factors with an order of magnitude better resolution than previously available.⁹ The quality of the CEBAF beam allows thin targets to be used, so a great abundance of isotopically pure targets are available. The chosen geometry for our work at CEBAF also allows secondary detectors surrounding the target to observe decay products from the reaction. The CEBAF experiment - Exp89-09, "Investigation of the spin dependence of the effective Λ -N interaction in the p shell", is one of the earliest

- 1) The Spectrum of $^{89}_{\Lambda}\text{Y}$ produced via the (K, π) Reaction. The various Λ single particle shells are obvious.

- 2) The Λ Separation Energies for Various Shells as a Function of $A^{-2/3}$. The curves are obtained from a density dependent Woods-Saxon potential.

approved experiments for Hall C. This proposal requested beam to be allocated in phases, and a total of 600 beam hours was approved for the first phase of the experiment. This phase proposed to measure spectra from one or two p-shell nuclei with a missing-mass energy resolution of approximately 1 MeV, although subsequent analysis has shown that our spectrometer system can provide significantly better resolution.

The unique features of E89-09 include;

- 1.) a optimized resolution of about 600 keV FWHM (a factor of three better than any previous or proposed measurements);
- 2.) spectra from the $(e,e'K^+)$ reaction which have never been previously obtained;
- 3.) spectra which include the excitation of the unnatural parity (spin flip) states due to the unique features of the photo-production mechanism, and;
- 4.) production of isospin mirror-pair hypernuclei, compared to those produced by the (K^-, π^-) and (π^+, K^+) reactions.

The general layout of the experiment has been described previously, and will not be discussed here. Although the experiment is designed to study light hypernuclei, in future experiments we would also propose the study of heavier hypernuclei with resolutions which would be much better than presently possible at other facilities.

In comparison to other counter experiments, Exp89-09 will have higher resolution (600 keV) and will excite an entirely new set of states. Both Exp89-09 and BNL Exp907, to be described below, produce the mirror pairs to the (K, π) and (π, K) experiments, which permit the study of charge symmetry breaking in hypernuclei, which in the s-shell hypernuclei is observed to be a factor of two larger than in normal nuclei. Also these different reaction mechanisms provide complementary information, and thus combined with spectra from the $(e,e'K^+)$ reaction, would provide a set of hypernuclear data sufficient for detailed analysis. The spectrometer, hardware, and software is essentially ready, and we await a run scheduling decision.

Experiment E907 at BNL is the first counter experiment to study the (K, π^0) production process. In this reaction a nuclear proton is converted to nuclear lambda - proton hole pair. All previous investigations have converted neutrons to nuclear lambda - neutron hole pairs. These complementary reactions produce isospin partners, where charge symmetry can be investigated. More importantly, however, the energy resolution of the (K, π^0) reaction will initially be about 1 MeV, substantially better than the 2-5 MeV of previous experiments, and the experiment has the potential to provide even better resolution in future investigations. One then expects that these precision measurements would provide new insight into the baryon interaction.

The BNL (K, π^0) experiments use the NMS apparatus, and potentially have sub-MeV resolution. However because a stopping Kaon beam is used, the size of the beam stopping volume severely restricts the number of possible targets.¹⁰ Still, the reaction strength is much greater, and thus the experiments are somewhat easier, than for electroproduction experiments. Of particular interest is an investigation of the role that the $\Delta I=1/2$ rule plays in non-mesonic hypernuclear decay. The key to such a measurement is an investigation of the ratio of the non-mesonic neutron-stimulated to proton-stimulated weak decay of the $^4_\Lambda\text{H}$ hypernucleus. This hypernucleus as well as

other s-shell hypernuclei can now be produced using the NMS apparatus.¹¹ The weak decay of hypernuclei is important because it has been argued that if quark effects can be observed at all in static nuclear properties, then they would be most evident in the high momentum transfer decay of hypernuclear levels.

The first NMS experiment, E907, has undergone an engineering run this year. All system components were tested, including the NMS itself, the data acquisition system, and the active target chambers. Preliminary analysis of these data show that the experiment worked as proposed, but a detailed study is now in progress to determine the experimental resolution, and the reaction rates. It is expected that the experiment will continue data acquisition during the AGS 1997 fixed target run beginning in February. During this time hypernuclear spectra from several targets will be acquired.

2) K^+ - Nuclear Scattering

A number of years ago our group was instrumental in measuring kaon and pion scattering from nuclear targets.¹² These data were used to extract optical model potentials which were used in the analysis of hypernuclear production via the (K,π) reaction. As is often the case, unforeseen results provided much more interesting information. The K^+ elastic data could not be fit with conventional multiple-scattering calculations using electron density measurements and K^+ -nucleon phase shifts, even though the multiple scattering series converged rapidly. Adding to the puzzle is the fact that K^+ scattering is mainly sensitive to the proton form factor, which is well measured by electron scattering. The total K^+ nuclear cross sections show similar deviations, and in-fact were undertaken as a result of our earlier elastic experiments.

This unexpected result was the subject of a number of theoretical speculations, all dealing with medium modification to the interacting nucleons.¹³⁻¹⁵ In particular it was suggested that it might be possible to relate the above results to an effective mass for the ω and ρ mesons involved in the Kaon-nuclear interactions, and thus change the range of the interaction.¹⁴ If true, this might provide a direct connection between Kaon scattering and the "EMC" effect.

Given the fact that these speculations were based on one data set, which was taken entirely for other reasons, we have completed a series of measurements on K^+ elastic and quasifree scattering to verify the results of the earlier data, AGS Exp 874. The K^+ quasifree scattering was completed first, and the data have been published.¹⁶ The quasifree scattering of particles from nuclei is a powerful means of exploring important nuclear structure since its theoretical interpretation does not require detailed information about individual nuclear levels. Aspects of nuclear structure, such as the effective NN interaction in the nucleus, then manifest themselves as departures from the quasi-elastic predictions for a non-interacting Fermi gas of nucleons. These results show that the K^+ is weakly very interacting as expected.

Our recent K^+ set of elastic measurements was undertaken to verify the earlier elastic data. Special attention was given to the normalization problem, and a new kaon beam line was used which had a much better kaon to pion flux ratio (1:1 instead of 1:5). Targets of ${}^6\text{Li}$ and C were used to study the density dependence of the reaction, and an incident momenta of 705 and 600 MeV/c were used to study the momentum dependence

of the scattering. In order to minimize the normalization error, only a 2 degree angle bin in the middle of the acceptance curve was used to extract a cross section from these data. The scattering strength to the various states in C is obtained by fitting the spectrum shape with a set of Gaussian curves positioned at the correct excitation energies of the states and a skewed Gaussian to represent the continuum. The result for the elastic scattering at 705 MeV/c from a C target as a function of the center of mass angle is shown in Figure 3. The data show only statistical errors. The un-correlated statistical errors of the data are small compared to the overall 15% systematic error, except at backward angles. No correction is made for the acceptance variation of $\pm 5\%$ across the angle cut.

The data are compared with calculations from two models of kaon-nucleus elastic scattering in the impulse approximation. The solid line is from a calculation by Jiang, Ernst, and Chen, which uses the Klein-Gordon equation and includes all first-order corrections.¹⁷ The dashed line is from a calculation by Kurth, Clark, and Hama, which uses the relativistic Kemmer-Duffin-Petiau (KDP) equation.¹⁸ Both calculations use the same kaon-nucleon phase-shifts taken from Arndt.¹⁹ The calculations using the KDP equation are motivated by the success of the Dirac-equation based analysis of proton-nucleus scattering. This equation resembles the Dirac equation in form, and one can construct the meson-nucleus optical potential in a manner similar to the relativistic impulse approximation (RIA). The meson-nucleus optical potential in the KDP approach consists of a cancellation between large scalar and vector (time-like) components. We wish to emphasize that, while the two calculations start with very different assumptions about the basic scattering equation, it is impressive that there is such good agreement between them.

Although ${}^6\text{Li}$ has a 1^+ ground state, and the calculations assume a 0^+ ground state, we expect that the data are well-modeled by the theories. At larger angles, effects due to the 1^+ ground state are expected to raise the data above the optical model calculations. Inelasticity in ${}^6\text{Li}$ dominates the excitation energy spectrum beyond 30° , and we do not attempt to extract elastic scattering beyond this angle.

In Figure 4 we present the ratios between natC and ${}^6\text{Li}$ elastic scattering compared to the model calculations. In this plot, only the statistical (i. e. un-correlated) errors apply. It should be noted that a small interpolation for the data points was required to produce the ratios for identical center of mass angles. From this figure the main point of this study may be drawn - the evident enhancement of the forward-angle elastic scattering ratios. This effect is clearly beyond statistical error limits and is not consistent with the model predictions. The impulse approximation is expected to be valid for calculations of K^+ -nucleus scattering below 800 MeV/c because of the long mean-free path of the kaon and the dominance of the S_{11} phase shift. However, the cross section ratios for C compared to ${}^6\text{Li}$ are up to 50% bigger than the calculations at the forward angles. The original K^+ scattering experiment of Marlow, et al.¹² reported results for carbon and calcium, which have nearly identical nuclear densities; here we compare nuclei of greatly differing densities.

These results support the recent K^+ total cross section ratio data which have been interpreted in terms of nuclear medium modifications. It is interesting to speculate on the reasons for the enhancement. Whether it is due to partial quark deconfinement, rescaling of meson masses, non-static meson exchange currents, or some other failure of the

3) The Angular Distribution of K^+ Elastic Scattering from C and ^6Li at 705 MeV/c. The curves are two theoretical predictions as described in the text.

- 4) The ratio between the K^+ Angular distributions of C and ${}^6\text{Li}$. The errors are statistical and show a deviation from the curve which represents the theoretical prediction.

modeling, is still unclear. We simply state here that we have established evidence, from the elastic scattering ratios, for the failure of present first-order models to treat K^+ scattering. Because of the uncertainty in the absolute cross section values, however, we are unable to apportion the effect quantitatively between carbon and lithium. We suggest that the great difference in nuclear densities lies at the heart of the problem.

B.) Test of the Standard Model of Electro-Weak Interactions

The acronym, MEGA, (LAMPF 969) is derived from the first letter of the branching ratio, $\mu \rightarrow e\gamma$ which was investigated in this experiment. The experiment was designed to be a background free measurement of this particular branching ratio to one part in 10^{13} . Presently, it appears that the experiment can achieve a limit to the branching ratio between 6×10^{-13} and 1×10^{-12} . A measurement to this accuracy would be about a factor of about 50 to 80 better than the present experimental limit.²⁰ The experiment tests the standard model of electro-weak interactions and may be interpreted in terms of a model characterized by new particles. In this measure, MEGA will raise the mass scales of new particle searches by almost an order of magnitude. MEGA is a collaborative effort of 11 institutions. The University of Houston, with help from Texas A&M University, was responsible for the construction and operation of the photon detector system. The photon detector system consisted of layers of cylindrical pair spectrometers with each layer acting independently and having the same geometry except for radial dimensions.

The general layout of the MEGA detector is shown in Figure 5. The lepton spectrometer, which is not discussed here, lies inside the pair spectrometers. A surface muon beam is brought to rest in a thin, slanted target foil, and the particles from the decays are tracked by the various detectors. The major components of a given pair spectrometer consist from small to larger radius, of a scintillation barrel, a cylindrical conversion foil, a multiwire proportional counter (MWPC), another conversion foil, a delay line for Z position measurement, a turning space with drift chambers (DC), and an outer aluminum cylinder for structural support and gas seal (CAN).

The scintillation strips provide timing and some axial position information, as well as help in pattern recognition of the event. The conversion foils are composed of 0.25mm Pb supported by a carbon fiber composite cylinder, and covered with at least a 1.8mm low mass foam layer. The foam thickness provides space for annihilation radiation pairs to circle without entering the active region of the wire chambers. A typical event showing one orbit of the conversion pair is shown in Figure 6. MEGA has collected data from 1992 to 1995. Figure 7. Is an illustration of the photon resolution of the pair spectrometers. It shows the detection of a 55 MeV photon from the back-to-back photon decay of π^0 formed in the $p(\pi^-, \pi^0)n$ reaction with a stopped π^- . An angle cut on the opening angle of the photons is made to produce nearly mono-chromatic photons.

A student from the University of Houston completed a doctoral dissertation in 1995 on MEGA data taken in 1992. Data acquisition in the 1992 run was considered an engineering run as the complete detector was not available, and data was accumulated for only two weeks. However, analysis of these data indicated that the major systems were operational, and it resulted in a branching ratio of less than 6.5×10^{-10} , a factor of 10 less

5) A Layout of the MEGA Experiment Showing the Major Components of the System.

6) A Typical Photon Event in the MEGA Photon Spectrometer. The end view shows the hit pattern in the wire chambers and scintillators, as the leptons spiral in the magnetic field.

- 7) **The MEGA Photon Spectrometer Energy Resolution for Incident Photons of 55 MeV.** The figure shows the resolution for conversions in both the inner and outer conversion foils. The resolution of the inner foil is poorer due to straggling of the leptons in the outer conversion foil.

sensitive than the present limit of 4.9×10^{-11} . While this result was not as sensitive as the present limit, it demonstrated that MEGA can reach the expected sensitivity. Analysis of the remaining data is proceeding. It is anticipated that this analysis will continue into 1997, but we anticipate that an intermediate result, more sensitive than the present limit will be available for publication soon.

C.) Measurement of the Nucleon Spin Structure Function

The Houston group has been a member of the Spin Muon Collaboration (SMC) experiment at CERN since its inception.²¹ The SMC is the third generation experiment to be performed on the original European Muon Collaboration (EMC) apparatus. It was motivated by the EMC measurements of the spin dependent structure function of the proton,²² $g_1(x)$, where x is the Feynman scaling variable. Those results were in disagreement with the predictions of the Ellis-Jaffe sum-rule,²³ the integral of $g_1(x)$ over all x , suggesting that the net contribution from the valence quarks was not sufficient to explain the spin of the proton. A further concern centered on the possible implications involved in whether the data were consistent with the more fundamental Bjorken Sum-Rule.²⁴ This sum rule is constructed by subtracting $g_1(x)$ for the neutron from that of the proton, and integrating over all x , and isolates the contribution to the matrix element for conversion of a down quark to an up quark.

SMC was devoted to deuteron data in 1992, 1994 and 1995. The data collected in 1993 and 1996 was used to verify and to extend the EMC proton data. A few weeks were spent using a transversely polarized target in order to evaluate the feasibility of measuring g_2 . According to present plans, SMC data acquisition will end in 1996.

The deuteron data through 1994 show a trend towards negative values for $g_1(x)$ at the smallest x values as shown in Figure 8. This is a critical observation because to compare the experimental results with the sum rules, which are the most model independent theoretical predictions, one must extrapolate to $x = 0$. The overall small values for $g_1(x)$ at larger x implies a disproportionate effect on the sum from regions of small x . Traditional extrapolation techniques average the last 2 points and assume they are constant as x goes to 0. As shown in Figure 8, the error bars are relatively large, but a negative trend is clear. Taking these latest results, the physics can be summarized in the following equations:

1. $\Gamma_1^d [0.003 < x < 0.7] = 0.0358 + 0.0087 \text{ (Stat)} + 0.0051 \text{ (Syst)}$
2. $\Gamma_1^d = 0.037 + 0.007 + 0.006 \text{ (corrected to } Q_0^2 = 10 \text{ GeV}^2)$

Using Γ_1^p from our prior published data²⁵:

3. $\Gamma_1^p - \Gamma_1^M = 0.180 + 0.032 \text{ (corrected to } Q_0^2 = 10 \text{ GeV}^2)$

One obtains Γ_1^M from $\Gamma_1^p + \Gamma_1^M = 2\Gamma_1^d / (1 - 1.5W_D)$ where W_D is the probability that the deuteron is in the D-state $\cong 0.05 + 0.01$. The measurement disagrees with the Ellis-Jaffe sum rule by three standard deviations. It is consistent with the Bjorken sum rule value of $0.187 + 0.003$ where the error is due to the uncertainty⁴ in α_s .

The naive Ellis-Jaffe sum rule assumed that ΔS , the contribution to the nucleon spin by strange quarks, was 0. If we rely on light-cone algebra and on $SV(3)_f$ relations for the axial vector coupling constants within the baryon octet, an analysis of the

8) A Plot of the Structure Function $g_1(x)$ vs x for the Neutron as Measured by the SMC Experiment.

contributions of the various quarks can be performed.²⁶ Including QCD corrections, our present data yield:

$$\Delta\Sigma = \Delta u + \Delta d + \Delta s = 0.23 + 0.08, \text{ and } \Delta s = -0.11 + 0.02.$$

D.) Summary

In conclusion, the group has been active and successful in a variety of experiments, large and small, in the past. We maintain a leadership role, in particular in our hypernuclear program, and are producing state of the art instrumentation for our work. We are graduating quality students trained in our field, both at the graduate and undergraduate level. We propose to continue this research program.

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IV. Publications (1994-1996)

"Construction of the MEGA Photon Detector", M. Barakat, et al, Nucl Inst and Meth, A349(1994)118

"Experimental Considerations in Electroproduction of Hypernuclei", E. V. Hungerford, Journal of Theoretical Physics (Sup), 117(1994)135

"Measurement of the Polarization of a High Energy Muon Beam", B. Adeva, et al, Nucl. Inst and Meth A343(1994)363

"Combined Analysis of World Data on Nucleon Spin Structure Functions", B. Adeva, et al, Phys Lett B320(1994)400

"Measurement of the Deuteron Polarization in a Large Target", B. Adeva, et al, Nucl Inst and Meth A349(1994)334

"Measurement of the Spin-dependent Structure Function $g_1(x)$ of the Proton", D. Adams, et al, Phys Lett B329(1994)399

"Spin Asymmetry in Muon-Proton Deep Inelastic Scattering on a Transversely Polarized Target", D. Adama, et al, Phys Lett B336(1994)125

"Quasielastic K^+ Scattering", C. M. Kormanyos, et al, Phys Rev C51(1995)669

" K^+ Scattering from Nuclei", E. V. Hungerford, Nucl. Phys. A585(1995)121c

"A Survey of Hypernuclear Physics", B. F. Gibson and E. V. Hungerford, Phys. Rep. 257(1995)350

"Charge Division Read-out in a 1.8 Meter Long Wire Chamber", K. A. Lan, et al, IEEE Transactions on Nuclear Science, 42(1995)1430

"A New Measurement of the Spin-Dependent Structure Function $g_1(x)$ of the Deuteron", D. Adams, et al, Phys Lett B357(1995)248

"A Large Acceptance Cylindrical Drift Chamber Detector", D. A. Ambrose, et al, Nucl Inst and Meth, A364(1995)265

"Architecture of the MEGA Detector Trigger", Y.K. Chen, et al, Nucl Inst and Meth, A372(1995)195

"Large Enhancement of Deuteron Polarization with Frequency Modulated Microwaves", B. Adeva, et al, Nucl Inst and Meth A372(1996)339

"Polarization of Valence and Non-strange Sea Quarks in the Nucleon from Semi-Inclusive Spin Asymmetries", B. Adeva, et al, Phys Lett B369(1996)93

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"K⁺ Elastic Scattering from C and ⁶Li at 715 MeV/c", R. Michael, et al, Phys Lett B382(1996)29

V. Invited Presentations

"Strange Physics at the AGS and CEBAF", E. Hungerford , Seminar, Sam Houston State University, February 1993

"What is So New About Hypernuclear Physics?", E. Hungerford, Seminar, Duke University", February, 1993

"Strangeness in Electroproduction", E. Hungerford , CEBAF Workshop/Retreat, May, 1993

"What is So New about Hypernuclear Physics?", E. Hungerford, Seminar, Vanderbilt University, October, 1993

"Where is MEGA? A Search for Lepton Family Violation", E. Hungerford, Seminar, Ohio University, February, 1994

"Positive Kaon Scattering and The Nuclear Medium", International Conference on Kaons and Hypernuclear Physics, E. Hungerford , Vancouver, Canada, July, 1994

"When does a Nucleon look Like a Nucleon ?", E. Hungerford , Texas Section APS, October, 1994

"MEGA - A Search for Lepton Number Violation in Rare Muon Decays" Nuclear and Particle Physics with Meson Beams, E. Hungerford , Tokyo, Japan, March 1995

"Up Date on Experiment E907" AGS Users Group Meeting, E. Hungerford, Brookhaven National Laboratory, June, 1995

"Nucleon Spin Form Factors from SMC", L.S. Pinsky, Baryons 95 Conference, Santa Fe, October, 1995

"Hypernuclear Studies at CEBAF - Hype or New Physics ?", E. Hungerford, CEBAF Workshop on Open Issues in Strange Particle Physics, October, 1995

"Hypernuclear Physics --- Hype-Or-New Physics?", E. Hungerford , Seminar, Indiana University, March, 1996